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ABSTRACT

The use and analysis of student generated propositions linking two scientific concepts (photosynthesis and respiration) were examined before and after the study of photosynthesis. A proposition-generating task (PGT) was used as a diagnostic tool to indicate student misconceptions and partial understandings. Focus was on determining: how the nature of the link between photosynthesis and respiration changes following instruction, and teachers' attitudes toward the PGT. A sample of 11th-grade and 12th-grade biology students participated in an evaluation of a curriculum for teaching photosynthesis and related concepts. One group of subjects (n=516) studied photosynthesis using the experimental materials, while a comparison group (n=147) studied photosynthesis using regular course materials. Students were asked to write propositions showing the relationship between photosynthesis and respiration before and after instruction. Propositions were grouped into categories reflecting understanding of the concept. Instruction with the experimental materials resulted in a decrease in major misconceptions, an increase in the frequency of goal concepts, and an increase in evidence of student understanding. The task was also well-received by teachers as a diagnostic measure. Four tables, one figure, and an 18-item list of references are provided. An appendix contains examples of student-generated propositions. (SLD)

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PROPOSITION GENERATING TASK (PGT):
A MEASURE OF MEANINGFUL LEARNING
AND OF CONCEPTUAL CHANGE

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INTRODUCTION

One of the aims of science education is helping students in constructing a stable and meaningful organization of concepts in their cognitive framework. Such a framework is, according to Ausubel (1968), the product of conscious and explicit linking of recently acquired knowledge to relevant concepts already existing in the student's cognitive structure.

Measuring this aspect of meaningful learning is not an easy task. The clinical interview is one way of eliciting cognitive structures but it is time consuming and not easily implemented with large groups.

Several methods which can be used with larger groups, have been suggested over the years (e.g. Shavelson, 1974; Hamrick et al,1987; Champagne et al, 1981). Word associations (WA) have been used more extensively than other methods (Shavelson, 1974, Schaefer, 1979, Gunstone, 1980, Johnstone & Moynihan, 1985, Gussarsky & Gorodetsky,1988) but were criticized for their inability to provide information about the **nature** of the link between the words (Stewart, 1979, Sutton ,1980). Stewart (1979) argued that "there are numerous valid propositions that could be generated to link two nodes. ...Which of the many possible relationships did the students have in mind? ... If one is interested in the nature of meaning in cognitive structure one must ensure that assessment devices assess the nature of that meaning"(p. 400).

Concept maps (Novak and Gowin 1984) appear to be such a tool representing both concepts and propositions. Linkages between concepts

in a concept map can reveal the existence of misconceptions or the missing of a key idea. One drawback of concept mapping is that it requires training and practice. Moreover, scoring of concept maps has been the focus of some debate. Stuart (1985) concludes by suggesting that a more holistic and qualitative scoring technique needs to be developed.

The present paper proposes the use of a Proposition Generating Task (PGT) as a diagnostic tool. PGT has been mentioned by Stewart (1980) in his review of methods for assessing cognitive structures. One might look at such a task as a spin-off from concept mapping, since in its simplest form a concept map consists of two concepts linked to form a proposition (Novak & Gowin, 1984).

It should also be noted that quite frequently the findings regarding students conceptions are reported in the form of propositions (Wandersee 1983, Ola-Adeniyi 1985, Bell, 1985, Haslam & Treagust, 1987). Hence, the PGT can generate propositions which render themselves to comparisons with prevalent notions.

In our study we have used a proposition forming task as diagnostic tool and found that propositions generated by students can be readily categorized according to the nature of the relationship between the two concepts and can effectively reveal misconceptions as well as partial understandings (Amir & Tamir, 1990). We are not aware of studies in which this task has been used in a similar way.

PURPOSE OF STUDY

The purpose of the study is to describe the use and analysis of student generated propositions linking the concepts photosynthesis & respiration before and after the study of photosynthesis. More

specifically the following questions were addressed:

1. How does the nature of the link between photosynthesis & respiration change following instruction?

2. What were the teachers'attitude toward the PGT?

The value and potential of the PGT as a measure of meaningful learning are discussed in light of the findings.

METHOD

Sample

The sample consisted of 663 11th or 12th grade biology highschool students (64% were in grade 11). These students participated in a comprehensive study aimed at improving understanding of photosynthesis and related concepts. There were two groups: Experimental (N=516) who studied photosynthesis using experimental materials and Comparison (N=147) who studied photosynthesis using the regular course materials.

The instrument and its administation

The task was presented to the students in the follwing manner: "Write a proposition which shows as well as you can the nature of the relationship between photosynthesis and respiration". Students were encouraged to add concepts by the following statement: " Try to generate sentences with more than 3-4 words and avoid sentences such as "photosynthesis and respiration are important".

In addition to the task described above multiple choice tests comprising 15 items (pretest) or 18 items (posttest) were used as well.

The tests were administered twice: before and after instruction. Instruction of the experimental group included using a special package of activities designed to enhance meaningful learning of photosynthesis and the relationships between photosynthesis and other processes and concepts, e.g. respiration, transpiration, autotrophy, energy. The teacher was given a guide which included, in addition to the suggested activities the following:

(a) Results of research on studnets' misconceptions regarding photosynthesis and hypotheses about their source.

(b) Up-to-date presentation of photosynthesis and related concepts and processes.

The comparison group studied in the regular fasion. Instruction time for the two groups was similar.

Data analysis

The propositions generated before and after the study of photosynthesis were analyzed on the basis of 4 criteria as follows:

1. What is the nature of the relationship exhibited by a certain proposition?
2. Does the proposition represent a valid and coherent relationship between photosynthesis and respiration?
3. Which additional concepts do students incorporate in the proposition before and after instruction.
4. How many additional concepts were added?

At the onset of the investigation we avoided the use of a rigid scheme and attempted to capture as many different notions as possible. The final set of 5 categories has emerged empirically from a variety of

students' notions. We started by reading about 200 propostions which enabled the identification of about 40 different notions. A close examination of these notions revealed some common features which justified grouping the notions into 5 categories as follows:

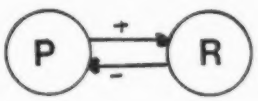
1. Lack of clear distinction between photosynthesis and respiration namely, photosynthesis is the same as respiration or respiration is seen as part of photosynthesis.
2. Opposite and contrasting aspects of photosynthesis and respiration.
3. Some common features of photosynthesis and respiration are indicated.
4. Photosynthesis and respiration are complementary processes in matter cycling and energy flow in nature.
5. "Other"

Category 4 represents the goal conception.

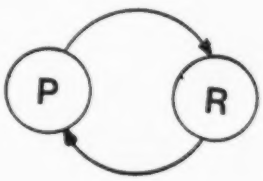
The order in which the first four categories are listed above reflects their relative proximity to the goal conception.

Figure 1 shows the four main categories in a graphic form.

Category 1:

Category 2: 

Category 3:

Category 4: 

P= photosynthesis R = respiration

Figure 1: A graphic description of the four categories.

Scoring

Scoring was carried out by assigning each proposition a mark on a scale of 0 to 4 were:

0=no proposition\incorrect, 1=no additional concepts and partially correct, 2= no additional concepts, correct, 3=correct and including one added relevant concept, 4= correct and including two or more added relevant concepts.

(See: Appendix)

Reliabilty

Reliabilty was established by subjecting a subsample of about 50 propostions to categorization and marking by 3 people (the two authors and an independent rater). Agreement was 75%.

Validity

In order to establish the validity of the task for measurment of understanding, correlations between the score on the PGT and the score on multiple choice tests (pretest and posttest) on photosynthesis were calculated.

Teachers' attitude

Teachers' attitudes towards the task were informally investigated.

RESULTS & DISSCUSSION

The multiple choice test

The mean percentage correct score in the pretest was 57.2.

The mean percentage correct score in the posttest was 78.1 and 71.2 for the experimental and the comparison groups, respectively.

The proposition generating task

Table 1 presents the results of the PGT.

Table I:
Frequency distribution of propositions by categories (in percentages), mean scores and standard deviations.

Category	Experimental pretest N=516	Experimental posttest N=516	Comparison posttest N=147
0. No proposition	17	0	3
1. Lack of distinction between photosynthesis & respiration	31	4	7
2. photosynthesis & respiration are "oppsites"	18	26	38
3. photosynthesis & respiration have common features	5	11	7
4. photosynthesis & respiration are complementary processes	18	54	37
5. Other	11	5	8
Score (scale 0-4)	.83	2.67	2.39
S.D	1.04	1.34	1.39
		t=24.63**	t=2.17*

*P<0.05, **P< 0.01

The results in Table I show the conceptual change that has occured in the students' congnitive structure regarding photosynthesis and respiration. The main changes in the experimantal group can be summarized as follows:

(a) a marked <u>decrease</u> in the frequency of category 1 propositions.

(b) a marked <u>increase</u> in the frequency of propositions in which the idea of complementarity between photosynthesis and respiration can be identyified.

(c) The notion that photosynthesis and respiration are opposite processes is more strongly held by students after instruction. Although not completely wrong, such notion can be regarded as less

desirable than the goal conception represented by category 4.

In the posttest the comparison group shows almost as low frequency as the experimantal group of category 1 (misconception) propositions which means that regular teaching was quite effective (at least in the short term) in removing this particular misconception. However, comparison group students exhibited substantially lower frequency in category 4 and a higher frequency of category 2.

These results clearly favor the use of the experimantal materials.

Table II presents the cross tabulation of the pre and post categorizations of propositions generated by the experimantal group students.

Table II
The distribution of categories in the pre and posttest

pre \ post	no proposition	1	2	3	4	other	Total
0.no proposition	6	1	19	11	47	2	86
1.	1	15	45	16	72	9	158
2.	1	1	30	9	47	3	91
3.	-	-	10	7	11	-	28
4.	-	1	16	5	70	3	95
5. other	-	3	14	7	29	5	58
Total	8	21	134	55	276	22	516

The data in Table II reveals some intersting trends of conceptual change:

(a) Twelve perecent of the students (63 students out of 516) whose propostions were categorized in the pretest to either categories:0, 1, 2, 3, or "other" did not change their conception.

(b) positive changes - from either "no proposition" or categories 1, 2 ,3 and "other" toward the goal conception namely category 4 - can be

observed for 206 (40%) of the students.

(c) Eighty four percent of the 158 students who had held the misconception represented by Category 1 abundoned it and wrote a correct proposition (either category 2,3 or 4).

(d) Most students (70 out of 95, 74%) whose propostions were categorized in the pretest in category 4 had a stable cognitive structure and wrote similar propositions in the post test. Yet sixteen (17%) of these falling into category 4 in the pretest wrote a category 2 propositionin the posttest. This result supports our previous observation that instruction strengthened among certain proportion of the students the image of photosynthesis and respirtation as opposite and contrasting. Further evidence of the resilience of this view is given by the thirty students who generated a category 2 proposition in both the pre and posttest.

(e) Ten percent of those who had held the misconception (category 1) in the pretest were still holding this notion after instruction.

As explained in the Method section the 5 categories (0-5) were extracted from the many ideas we have found in the student generated propositions. Although the total number of different ideas was close to 40 only a few of them appeared in more than 5 percent of the propositions. Table III presents the most frequent propositions in the pretest and in the posttest. These propostions are also used to demonstrate how the final categorization was made.

The data in table III lend further support to the conceptual change that has occured. First, none of the most frequent propositions found in the posttest belongs to category 1.

Second, two types of propositions appear frequently in both the pre and

posttests (42 & 44). It may be noted that the frequency of propositions 42 & 44 is much higher in the posttest. These propositions seem to reflect the way many students conceive the relationship between photosynthesis and respiration.

Table III
The most frequently generated propositions (Category in parentesses) and their frequencies.

No. of proposition		percentage
pretest		
11(1).	Photosynthesis is the respiration of plants	20
12(1).	Respiration is part of photosynthesis	8
24(2).	In photosynthesis oxygen is given off and CO_2 is taken in and in respiration oxygen is taken in and CO_2 is given off.	6
42(4).	The gases used in one process are the ones given off in the other	10
44(4).	The materials produced in one process are used in the other	5
51(5).	Photosynthesis is neccessary for respiration	6
postest		
22(2).	Photosynthesis occours during the day, respiration takes place all the time	5
24(2).	In photosynthesis oxygen is given off and CO_2 is taken in and in respiration oxygen is taken in and CO_2 is given off.	7
42(4).	The gases used in one process are given off in the other	13
44(4).	The materials produced in one process are used in the other	22
48(4).	Materials and energy for respiration are supplied by photosynthesis	5

In the directions to the assignment students were encouraged to generate propositions which include additional concepts. Relevant added concepts contributed to the score. For a subsumple of 128 students we analyzed the added concepts. The most often used concepts by this subsample are presented in Table IV (only concepts uses by at

least 10% of the subsample were included).

Table IV
Frequency of concepts added to the propsitions (in percentages)

Concept	pretest	postest	Relative increase
CO_2	21	28	
O_2	22	33	
sugar/organic materials	16	47	*
breakdown of materials	6	14	*
raw materials	3	11	*
energy	8	32	*
oxidation	3	12	*
light/sun	10	10	
plant	45	20	
Total no. of concepts added	196	319	

* increase is larger than expected from the increase in the total no. of concepts (=63%)

Table IV provides additional insight into the changes in students' cognitive structures. These changes can be described, in Ausubel's (1968) terms as progressive differentiation and integrative reconciliation. The number of relevant concepts increased by 63%. Moreover, concepts related to material cycling and energy flow were included in posttest propositions in even higher proportions. The decrease in the occurence of the concept "plant" in the posttest can also be regarded as evidence for the broader world view developed by the students.

Validity

The concurrent validity of the propositions generating task can be established by correlating the achievemant in the task with performance on other measures of understanding photosyntheis and respiration. The

task was part of a photosynthesis test and the correlation between the score on the task and a subtest of 18 items multiple choice items on photosynthesis and respiration was .35 ($P<0.01$).

Teachers' attitudes

Teachers found the PGT neither difficult nor too easy and expressed their appreciation of its potential in revealing misconceptions effectively and efficiently being rather quick, easy to administer and convenient to score.

Furhter evidence regarding the utility of the task for classroom use was provided by the decision of some teachers to photocopy a collection of propositions written by their own students and use them for feedback and as a basis for classroom discussion.

SUMMARY AND CONCLUSIONS

Based on the results the PGT may be regarded as a useful and valid measure of conceptual change. The outcome of instruction using the experimental material were the following:

1. A decrease in the frequency of category 1 (major misconception) propositions.
2. An increase in the frequency of category 4 (goal conception) propositions.
3. The image of photosynthesis and respiration solely as opposites (category 2) seems to be very resilient and difficult to change. It is one that often appears in textbooks. We believe that this notion interferes with meaningful understanding of the comlementarity between photosynthesis and respiration
4. Further evidnece of the growth and development of students

cognitive frameworks as a result of studying the experimental program, is provided by the number and the nature of the concepts added in the posttest.

5. The proportion of correct propostions has increased significantly.
6. The PGT task was well received by the teachers.

Diagnostic testing is essential for ascertaining meaningful learning. Assessment of prior knowledge and of meaningful learning requires the use of innovative strategies. The proposition generating task (PGT) has been shown to be an effective measure. Some of its unique advantages over other strategies are the following: It requires neither special training nor practice and can probably be used with younger students as well. It is not time consuming and is relatively simple to assess once we have identified the possible misconceptions and decided about the goal conception. The last premise implies that the vast amount of information about students' misconceptions can be put to practical use in the manner described in this paper.

Further research is needed to compare the effectiveness of PGT relative to other diagnostic measures.

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APPENDIX

Examples of student generated propositions their categories and scores assigned to each.

	Score
Category 1: Lack of distinction between photosynthesis and respiration	
* photosynthesis is the respiration of plants in light.	0
* photosynthesis is the process by which the plant breathes(*) e.g. the plant takes in CO_2 and gives up O_2.	0
* photosynthesis is a processs of respiration in plants utilizing light.	0
* While plants carry out photosynthesis they also respire. Respiration has to take place for photosynthesis to occure	0
* photosynthesis is done with the help of CO_2 and O_2 is given up and this is repiration.	0

Remark:
* In Hebrew there is only one word for breathing and respiration. This adds to the student's confusion. In teaching, "cellular respiration" is used for respiration to help distinguish between the two processes.

Category 2: Opposite and contrasting aspects of photosynthesis and respiartion.	
* photosynthesis is carried out by plants in the light and respiration is carried out by animals 24 hour a day. [One concept was added, but respiration in plants not mentioned.]	1
* photosynthesis is carrried out by autotrophs. Respiration takes place in producers and consumers. [correct and three additional concepts]	4
* In photosynthesis and respiration the samo chemical reactions take place but in opposite directions. [Incorrect].	0
* In photosynthesis glucose is formed and O_2 is released while in respiration glucose is broken down and CO_2 is released [Correct and concepts were added. No cycling of materials between processes.]	4
Category 3: Common features of photosynthesis and respiration.	
* Respiration & photosynthesis are two proccesses by which the plant produces energy for its existence. [The processes differ in their role as regarding anergy transformations].	0
* Respiration & photosynthesis are two processes found in plants and enablo it to live and grow. [correct statement but lacks meaningful attributes of the	1

proccesses.]

* ATP is produced in both photosynthesis and respiration. 3
  [Correct and relevant concept (ATP) added]

Category 4: Photosynthesis and respiration are comlementary proccesses in matter cycling and energy flow in nature.

* The materials released in photosynthesis are used in plant's respiration. 3
  [Idea of cycling clearly stated but details are missing]
* The products of photosynthesis (sugars) are oxidized during respiration to release energy. 4
  [Sugar and oxudation are added in the correct propostion]
* photosynthesis supplies materials and energy for respiration. 4
  [" materials" and "energy" were included and idea of complememtarity expressed]